SAO-AXAF-FR-92-004
7 April 1992
NAS8-36123
Type 3 Document
DR#4-Final Report

DR# 4 - Final Report:

Volume I - Preliminary Design Study: AXAF X-ray Calibration Spectrometers

Volume II - Revised Preliminary Design Study: AXAF X-ray Calibration Spectrometers

(NASA-CR-184340) VOLUME 1. PRELIMINARY DESIGN STUDY: AXAF X RAY CALIBRATION SPECTROMETERS. VOLUME 2. REVISED PRELIMINARY DESIGN STUDY: AXAF X RAY CALIBRATION SPECTROMETERS Final Report (Radiation Science) 34 p

N92-33094

Unclas

G3/89 0110077

Prepared for:
George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Marshall Space Flight Center, AL 35812

Submitted by:
Smithsonian Astrophysical Observatory
60 Garden Street
Cambridge, MA 02138

34

Foreword

The objective of this work, begun in July of 1991, was to provide a preliminary design concept for a Flux Monitor Spectrometer (FMS) for use at the XRCF during HRMA testing, that met the requirements of SAO-AXAF-88-025 dated 7/31/91. The initial study, as approved by MSFC, was subcontracted to Radiation Sciences (SAO subcontract S01-15526). This work was completed in October 1991 and a Final Report (RS-30) was received from Radiation Science in early November 1991.

During the course of this study, the Calibration Task Team determined that the spectral resolution of the FMS had to be greater than or equal to twice that of all the AXAF spectrometers throughout the 0.1 to 10 KeV range of X-ray energies. Since this effectively doubled the resolution required by SAO-AXAF-88-025, a change order was approved by MSFC and given to Radiation Sciences in February 1992 to revise their study. They completed this Phase II study and submitted a Final Report (RS-32) in early April 1992.

This DR submittal consists of both reports.

Volume I - Preliminary Design Study:
AXAF X-ray Calibration Spectrometers
November 1991

RS-30

FINAL REPORT
Subcontract S01-15526

PRELIMINARY DESIGN STUDY:
AXAF X-ray Calibration Spectrometers

Radiation Science, Inc.
P.O. Box 293
Belmont, MA 02178

Prepared for:
Smithsonian Institution
Astrophysical Observatory
60 Garden Street
Cambridge, MA 02138

Technical Monitor:
Dr. E. M. Kellogg

Contents

1 Summary

This document comprises the final technical report for Smithsonian Astrophysical Observatory purchase order S01-15526. The object of this work was to provide a preliminary design of the physical interfaces between the AXAF X-ray Calibration Facility and X-ray wavelength dispersive spectrometers which will be used to monitor the spectral output of the X-ray sources used to calibrate AXAF. Radiation Science was required to submit a written report of the design providing a clear and detailed description of the vacuum interface, the placement of the instruments relative to the X-ray sources, the estimated weight and mechanical envelope of the instruments, as well as requirements for mounting stability, temperature and humidity, electrical power, and any other requirements which might effect the interface to the facility. This document is the required report.

In order to start this work Radiation Science had to generate a conceptual design for the spectrometers that met the instrument performance requirements laid out in the 31 July 1991 draft of SAO-AXAF-88-025. Because the X-ray sources have not been selected at this time, we assumed a generalized X-ray source of diameter 0.5 mm, located 1731 feet from the central plane of the HRMA.

Based on discussions with SAO personnel, we assumed that, for monitoring purposes, the spectrometers could be exposed to the X-ray source output in the annular region outside the cone defined by the X-ray source at its apex and the clear aperture of the gate valve at the interface between the long tube and the XRCF instrument chamber at its base and inside the radius defined by the cutoff of the X-ray beam due to the limiting aperture produced by the hole in the laser turning mirror. We assumed that the clear aperture of the gate valve was 57.5 inches at a distance of 1707.33 feet from the X-ray source. We further assumed that the laser turning mirror was located ten feet forward of the X-ray source. In order to provide sufficient room for the spectrometer apertures, we recommend that the diameter of the hole in the laser turning mirror be increased from 5/8 inch to 1 inch.

In addition to their placement in the annular region outside the beam to the HRMA, the spectrometers will be equipped with translation apparatus which would allow them to be moved into the axis of the X-ray beam in order to avoid any discrepancy in calibration due to a variation of the source spectrum as a function of angle.

In order to estimate the time required to measure spectral line intensities to a precision of 1%, we assumed that the X-ray source would be as strong at any line of interest as

the source used to calibrate the VETA. That source was measured at the K_α line of aluminum to produce 70 photons-cm^{-2}-sec^{-1} at 1700 feet. We assumed that the calibration source would generate at least this much photon flux in any spectral line of interest.

We selected a spectrometer array consisting of both crystal and grating spectrometers. The crystal spectrometer will cover the wavelength range between 1.2 Angstroms (10 keV) and 24 Angstroms (500 eV). Three crystals are necessary to maximize the resolution of the system. The grating spectrometers will cover the range between 20 Angstroms and 150 Angstroms. Two grating instruments with different grazing angles will be required to optimize throughput.

Although an exhaustive analysis of spectrometer designs was outside the scope of this study, we considered several grating and crystal configurations. For simplicity, we considered a crystal spectrometer using single reflections from plane crystals. The three crystals selected were silicon, ADP (Ammonium Dihydrogen Phosphate) and RAP (Rubidium Acid Phthalate). Three grating spectrometers designs were considered. They were the classic Rowland circle design, the Hettrick and Underwood HIREFS design, and the Pouey design. We selected the Pouey design. It consists of a toroidal mirror illuminating an aberration corrected, holographically formed, plane grating to produce a flat spectrum suitable for read out by an area detector. In order to cover the spectral range from 20 to 150 Angstroms with good throughput, two grating spectrometers of different grazing angle were selected.

A 32 inch diameter port (designated 78K) has been provided for diagnostic instrumentation. It is located in the bottom of the tube at Station 26+85.56, approximately 14.5 feet from the end of the 3 ft. diameter tube. The crystal spectrometer can be mounted on this port. Because of the great length of the grating spectrometers, however, only a portion of these instruments can be accommodated here. We considered two alternatives. The entire grating spectrometer could be placed on a base plate approximately four meters in length and 20 to 25 cm wide cut into the side of the tube. Alternatively, the optical assembly of the grating spectrometer could be attached to the same plate as the crystal spectrometer while the entrance slit assembly is attached to a 16 inch diameter port in the top of the tube at approximately Station 26+93.1 and the detectors are attached to a 24 inch port in the top of the tube at approximately Station 26+79.8. These positions are only approximate at this time. The final positions of these additional ports may change by up to 0.5 feet in either direction as a result of final instrument design.

The detailed design of the grating spectrometer may indicate that a different placement of the optics, or a different design is preferable. The long base plate mounting alternative provides for greater flexibility in the final design of the

spectrometer at the expense of a significant modification in the vacuum pipe. On the other hand, if the final location of the two top ports for the slit assembly and the detector assembly can be deferred until after the design of the grating spectrometer is finalized, we strongly recommend the "three port" design.

Only two other modifications to the present calibration facility design are required to accommodate the source calibration spectrometer system. First, the central hole in the laser turning mirror must be enlarged to one inch in order to provide adequate X-ray coverage of the spectrometer entrance apertures. Second, the apertures of the X-ray flux monitors located 130 feet from the X-ray source may be obscured by these calibration spectrometers. If this is the case, the apertures of the flux monitors will have to be repositioned. The calibration spectrometers do not use the portion of the X-ray annulus near the "twelve o'clock" position. We recommend that the X-ray flux monitors be moved to this position.

In addition, we recommend that the position of the X-ray source relative to the turning mirror should be specified and fixed prior to the final design of the calibration spectrometers.

We do not anticipate any difficulty meeting the temperature requirements of the 31 July 1991 draft of SAO-AXAF-88-025. In the recommended three port design, the weight carried by the base plate of port 78K is approximately 40 kilograms. The plate supporting the aperture subsystem will carry about 20 kg and the weight of the detector subsystem is estimated to be approximately 25 kg. Electrical interface requirements are discussed for each spectrometer individually below.

Figure 1 shows the overall layout of the calibration spectrometers. Table I summarizes the interface between the spectrometers and the calibration facility.

2 Crystal Spectrometer

Section C of figure 2 shows the design concept of the crystal spectrometer. It consists of three plane crystals on a common shaft. Diffracted X-rays are detected by end window proportional counters.

The design of the crystal spectrometer is driven by the spectral resolution requirement. The spectral resolution of the system, $\lambda/\delta\lambda$, should be greater than or equal to 2000. The spectral resolution is equal to the tangent of the Bragg angle divided by the angular resolution of the Bragg angle. The angular resolution has a mechanical component, a component due to the natural diffraction spread of the crystal, and a component due to the angular size of the source. For a given level of resolution, greater angular divergence is permitted at large

Bragg angles. The minimum Bragg angle is set by the shortest wavelength that must be observed. In this case, a Bragg angle of 11.4 degrees is required to diffract 10 keV X-rays from a silicon crystal with a 2d spacing of 6.26 Angstroms. At this angle, only 20 arc seconds of angular divergence can be permitted. If the crystal spectrometers are located at Station 26+85.56, a 0.5 mm source located ten feet behind the end of the three foot diameter tube will subtend only 15 arc seconds. Moreover, at this distance, a geometrical collecting area of one cm^2 will provide about 4 x 10^5 photons per second in the spectral line. This area should be adequate to provide 1% statistical precision in the spectral measurement in a time span of 300 seconds.

Conventionally, high resolution crystal spectrometers rely on the use of two or three Bragg reflections to reduce the effect of the diffraction width of the crystal. In this case, the source size is the principal contributor to the resolution at the highest energy, so a one reflection design was chosen. Also, because the source is approximately 25 feet from the crystal, the Rowland circle is quite large. Plane crystals can be used.

The short wavelength end of the angular range of the spectrometer was determined by the requirement to disperse 10 keV X-rays. We arbitrarily set the long wavelength limit of the angular range at 80°. Crystal spectrometers perform best at large Bragg angles, but as the maximum angle increases, it becomes more difficult to avoid mechanical interferences.

Silicon was selected as the best material for the short wavelength crystal. It is easy to obtain high quality crystals in large sizes. The diffraction width at 10 keV is less than 10 seconds of arc for properly selected crystals. The silicon crystal will diffract X-rays between 2 and 10 keV.

There are a variety of crystals that can be used at intermediate wavelengths. We selected ADP (Ammonium Dihydrogen Phosphate) because it has a reasonably narrow diffraction width, and it is readily available. It's 2d spacing is 10.64 Angstroms. Accordingly, between 10° and 80°, it will diffract X-rays between 1.2 and 6.7 keV.

In general, it is not feasible to achieve a resolution of 2000 with a crystal spectrometer in the energy range below 1 keV. RAP (Rubidium Acid Phthalate) crystals, however, can achieve resolution of nearly 1000 at 600 eV. This crystal will diffract X-rays with energies between 0.5 and 2.7 keV.

The three crystals will be mounted on a common shaft. The axis of rotation will be parallel to the crystal planes, but the crystals will pivot about different points on their surfaces. See figure two. They will be coaligned in the laboratory, prior to installation. In this way, all three crystals can be aligned to the beam from the X-ray source with a single set of alignment stages. In addition, a single mechanism will move the X-ray

detectors for all three crystals at twice the angular velocity of the crystal rotation.

The diffracted X-rays will be detected by end window proportional counters. The size of these counters is determined by the need to intercept the beam at all angular positions. The counter window materials, lengths and fill gases are determined by the efficiency requirements at the extremes of the energy ranges. We have tentatively selected counter lengths of one inch. The two counters that detect X-rays with energies above 1 keV will be sealed. The sub-kilovolt counter may have to be a flow counter. Preamplifiers will be mounted in the vacuum, close to the counters but outside the X-ray beam.

We considered the possibility of using a long, fixed counter for each of the three energy channels. This would have the advantage that the mechanisms in the area near the beam would be reduced and we might be able to increase the geometrical area of the crystal spectrometers. This approach has the drawback, however, that each wavelength is detected by a different point on the detector. Photometric calibration requires the characterization of each position along the length of the counter separately. Moreover, by staggering the position of the crystals on the shaft, we were able to obtain adequate crystal area.

The entire crystal spectrometer is mounted to the base plate through a set of stages which translate the spectrometer perpendicular to the beam and which rotate the spectrometer so that the crystal shaft is perpendicular to the beam. The absolute accuracy of the alignment of the crystals to the beam is not particularly critical, since this quantity is determined by in situ calibration at the start of each run, but the crystal spectrometer is relatively sensitive to variations in alignment due to wobble or microphonics. No more than 10 arc seconds of movement in the orientation of the crystal axis can be permitted when the Bragg angle is small. This requirement is reduced as the minimum angle of crystal rotation increases.

Two 61 pin Deutch connectors will be required to convey low voltage power and logic signals to the crystal spectrometer. In addition, 3 SHV feedthroughs will be needed to carry high voltage to the proportional counter detectors. Nine tri-axial feedthroughs are required to carry data, timing information and signal injection. Two #4 VCR feedthroughs will be required for the sub kilovolt flow proportional counter. All of these feedthroughs should be mounted on the same baseplate as the spectrometer mechanism.

Instrument control and data acquisition can be handled by any small laboratory computer such as a PC or a Macintosh. Such a computer could be co-located with the experiment electronics rack adjacent to the diagnostic port (78K). Alternatively, signals to and from the electronics can be transmitted through an

ethernet interface to the control room where they could be used by a workstation.

3 Grating Spectrometers

The overall layout of the two grating spectrometers is shown in figure 1. Two spectrometers will be used. One spectrometer will cover the wavelength range from 20 to 60 Angstroms. The other will cover the range from 50 to 150 Angstroms. It is reasonable to expect good spectra over a factor of three in wavelength.

The spectrometers are of the Pouey design. A toroidal mirror is used together with a holographically formed plane grating to disperse a nearly stigmatic spectrum onto a flat focal plane suitable for detection by a two dimensional imaging array. Sections A and B of figure 2 show the aperture plate and the orientation of the toroidal mirrors. Sections D and E (on figure 3) show the configuration of the plane gratings and the detectors.

The aperture plate will hold the two spectrometer entrance slits. Each slit will be 10 microns in width and one millimeter in length. Apertures for the crystal spectrometers will be mounted on the same aperture plate. The aperture plate will be mounted on motorized stages so that the apertures can be positioned to illuminate the toroidal mirrors. The aperture plate will be attached to a port on the top of the tube at Station 26+93.1

Each of the toroidal mirrors will be optically aligned with its corresponding plane grating during assembly. Each mirror and grating pair will be mounted together as a unit which can be aligned to focus the spectrum on the detector. These optical elements will be mounted at the existing port at Station 26+85.56 along with the crystal spectrometers. Both the toroidal mirrors and the gratings are made of fused quartz and are coated with gold. The overall length of the spectrometer depends on the choice of grating period and on the resolution of the area detector selected to read out the spectrum. These quantities determine the overall resolution of the spectrometer. We arbitrarily selected a nominal grating pitch of 2400 grooves per mm and a detector resolution of 25 - 30 microns per pixel. The system length could differ significantly if a different groove density grating or a higher resolution detector had been used.

The detectors will be mounted at a new port at Station 26+79.8. SAO has requested that we consider the use, if possible, of the HRI detectors. The HRI has adequate resolution for this purpose. Because the sensitive area of the HRI detector is 25 mm in diameter, it will be necessary to translate the detectors along the dispersion direction in order to image the entire spectrum. The spectrum is more than 40 mm in length so

that it is unlikely that a soft X-ray detector can be obtained that combines adequate resolution and sufficient length. In addition the detectors will be capable of movement for focussing and placement of the spectrum.

The new port holding the aperture plate at Station 26+93.1 will require two 61 pin connectors to provide power and positioning information. Two additional 61 pin connectors will be required at port 78K to service the mechanisms which position the mirror-grating optical systems. The new port at Station 26+79.8 will need at least three 61 pin Deutch connectors, two SHV connectors for detector high voltage, and four tri-ax connectors. Some detectors may require additional connectors.

The data will take the form of four images of the spectrum every spectrum measurement interval (five minutes). While these spectra cover the full extent of the detector in the direction of dispersion, they need only cover a fraction of the detector in the opposite direction, e.g. the central quarter. Thus the total data volume is approximately equivalent to one full HRI image every five minutes. Software will be required to convert the detector images to spectra by summing data as a function of wavelength. Macintosh software for this purpose already exists at Radiation Science. This software is adaptable to other computer systems.

4 Spectrometer Interface Parameters

VACUUM INTERFACE:

The spectrometer will be attached to port 78K at Station 26+85.56. Two additional ports will be required on the top of the tube. A 16 inch diameter port at Station 26+93.1 and a 24 inch port at Station 26+79.8.

SPECTROMETER WEIGHT:

Port 78K: 40 kg
New port at 26+93.1: 20 kg
New port at 26+79.8: 25 kg

MECHANICAL ENVELOPE:

See figures.

STABILITY:

The relative positions of port 78K and the ports at Station 26+79.8 and Station 26+93.1 must not change by more than 10 microns in the Y-direction or the Z-direction over the five minute data sampling interval.

The orientation of the axis normal to the baseplate of port 78K may not rotate about the Y or Z axes by more than 10 arc seconds over the five minute data sampling interval.

TEMPERATURE:

Operating -- 70±5 F
Operating Stability -- ±2 F

Storage -- 70±5 F

ELECTRICAL:

Port 78K -- 4 61 pin
3 SHV
9 tri-axial

Aperture port
2 61 pin

Detector port
3 61 pin
2 SHV
4 tri-axial

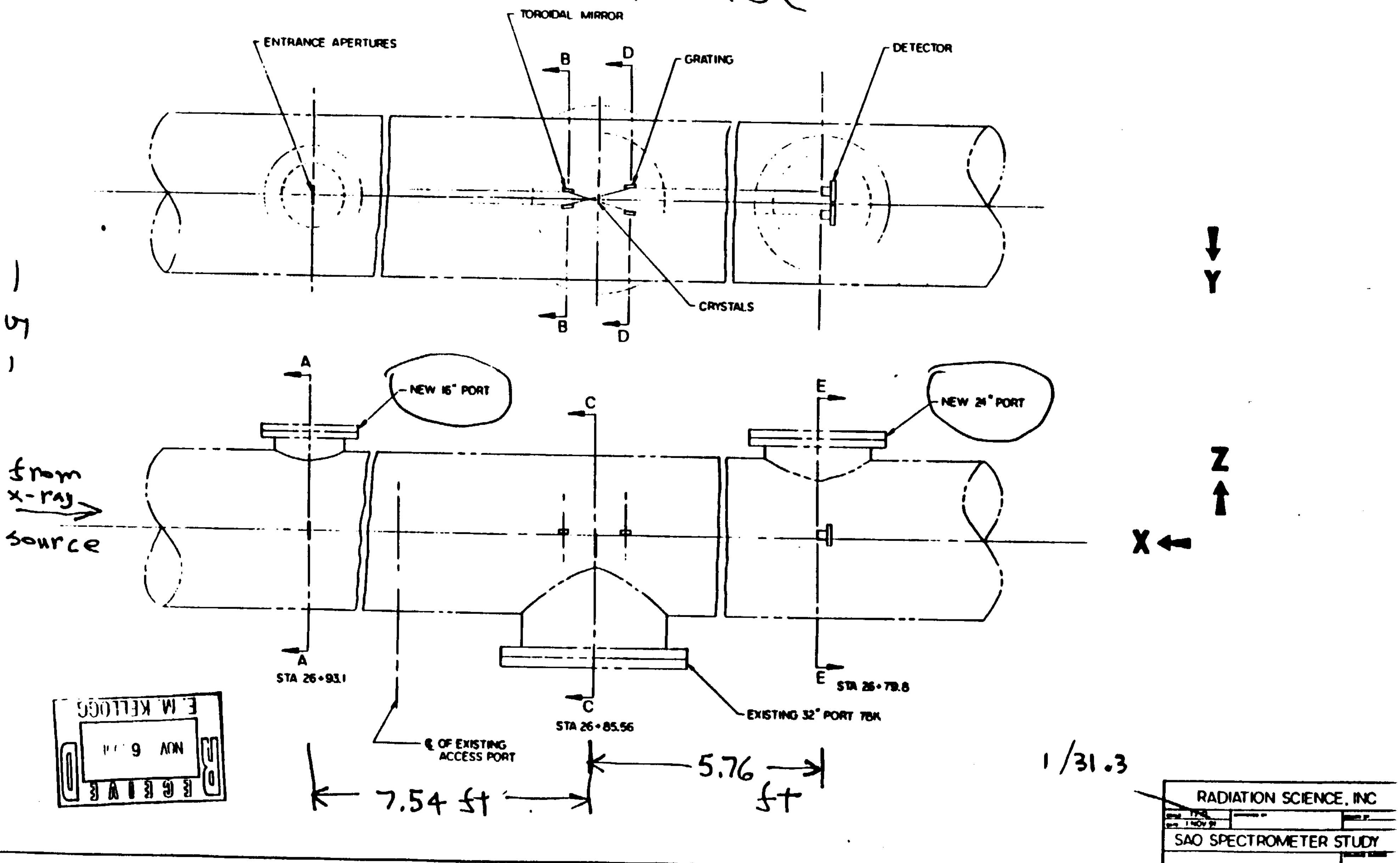
GAS:

2 VCR #4 feedthroughs on Port 78K

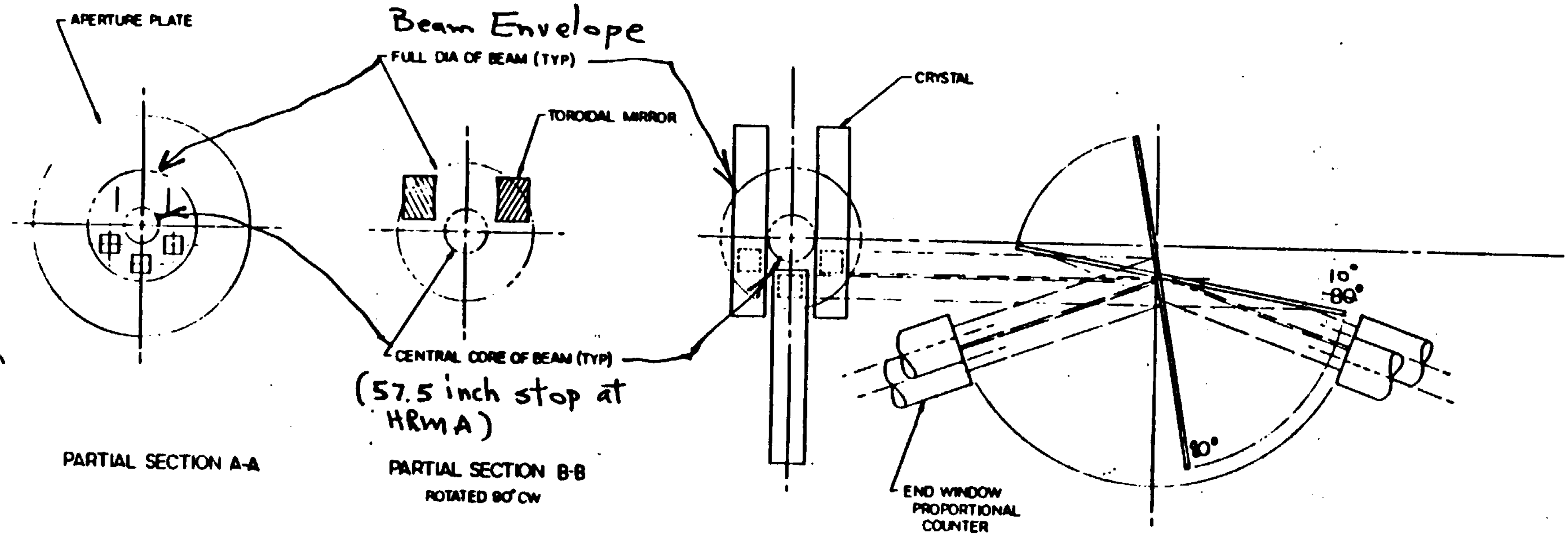
DATA:

TBD (see text)

Scars to Guide Tube



FMS Apertures, Components, Beam Paths. I.

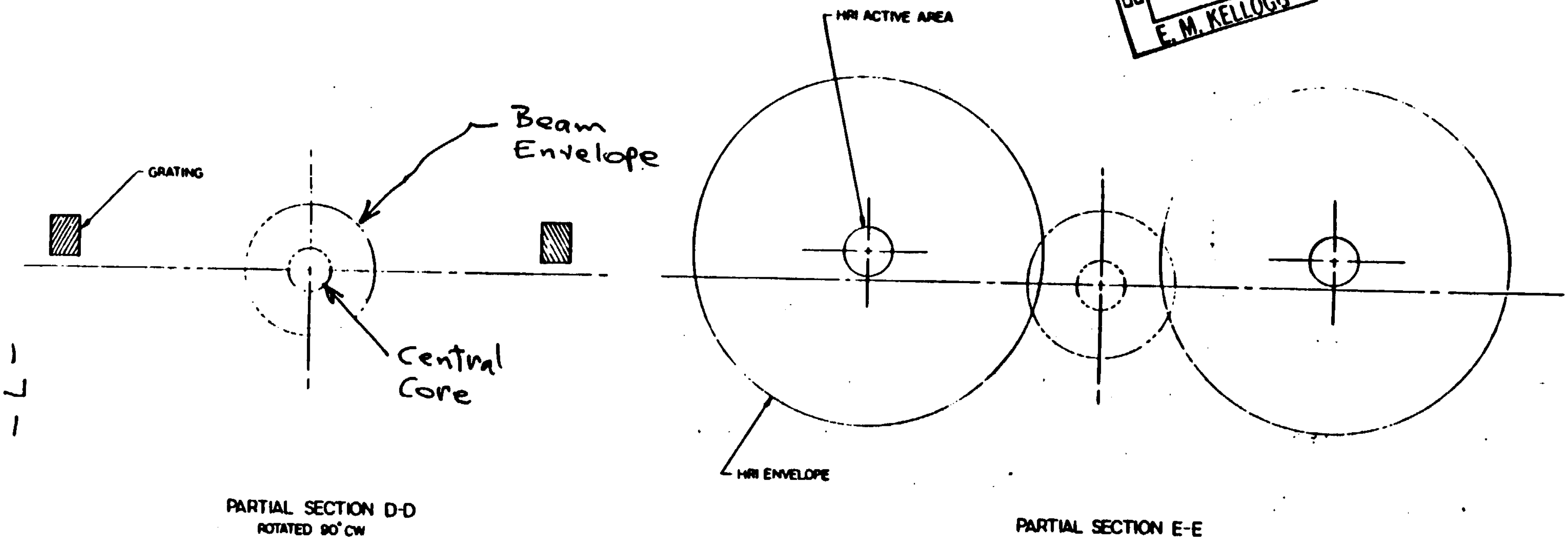


Note: Aperture plate needs a hole to illuminate the XFM.
The XFM will need to be moved to a different YZ location, at the same X location.

1/3.13

RADIATION SCIENCE, INC
SECTIONS A,B & C

Fms Apertures, Components, Beam Paths. II



1/3,13

RADIATION SCIENCE, INC

SECTIONS D&E

Volume II - Revised Preliminary Design Study:
AXAF X-ray Calibration Spectrometers
April 7, 1992

RS-32

FINAL REPORT
Subcontract S01-15526
Change Order No. 1

REVISED PRELIMINARY DESIGN STUDY:
AXAF X-ray Calibration Spectrometers

April 7, 1992

Radiation Science, Inc.
P.O. Box 293
Belmont, MA 02178

Prepared for:
Smithsonian Institution
Astrophysical Observatory
60 Garden Street
Cambridge, MA 02138

Technical Monitor:
Dr. E. M. Kellogg

Contents

1 Summary

The characterization of the output of the X-ray sources used to calibrate AXAF is an important aspect of the calibration program. The output spectrum of the calibration sources should be known with an uncertainty which is small compared to the desired precision of the calibration and with a spectral resolution higher than that of the AXAF spectrometers. In addition, temporal variations of the source spectrum must be monitored in real time and integrated over the duration of the calibration measurement.

This document comprises Radiation Science's final technical report for change order #1 to Smithsonian Astrophysical Observatory purchase order S01-15526. The object of this work was to modify the preliminary design concept of the AXAF calibration Flux Monitor Spectrometer System (FMS) so that the spectral resolution of the FMS was greater than or equal to twice that of all AXAF spectrometers throughout the 0.1 to 10 keV range. The FMS will be used to monitor the spectral output of the X-ray sources used to calibrate AXAF.

Radiation Science was required to submit a written report giving a clear and detailed description of the vacuum interface, the placement of the instruments relative to the X-ray sources, the estimated weight and mechanical envelope of the instruments as well as requirements for mounting stability, temperature and humidity requirements, electrical power and other facility requirements. This report supersedes technical report RS-30 which provided similar information for an FMS satisfying the original requirements.

Just as more than one X-ray source will be necessary to cover the AXAF energy range, more than one spectrometer will be needed to characterize the source spectrum over the entire energy range. Three crystal spectrometers are used to measure the source spectrum at energies greater than about 500 eV and two grating spectrometers are used below about 600 eV. The overlap in the energy ranges of these instruments, will facilitate cross-calibration.

Several changes were made to the previous design. Double, plane crystal, Bragg spectrometers were substituted for the single crystal spectrometers considered before. The grating spectrometers' field angles, toroidal mirrors and gratings were changed to reduce the effects of coma on the instrument resolution. An additional flat mirror was added to the optical path of each grating spectrometer to facilitate their placement. The analysis of these changes demonstrated the need for modifications to the packaging of the HRI. This latter change cannot be attributed to the increase in spatial resolution,

however. It was a change in the design that would have been necessary in any event. It was simply uncovered at an earlier stage than otherwise because of the re-examination of the grating spectrometer design.

The modifications to the spectrometer design have produced some changes in the mechanical interface between the FMS and the test facility. Specifically, the orientation and location of the two ports that must be added to the vacuum tube have changed. The new spectrometer interface parameters and the changes in them from those of the previous study are tabulated in Section 4. These changes will facilitate the installation and alignment of the modified FMS. This does not imply that a decision on the ultimate spectral resolution of the FMS is required before the guide tube can be specified. The preliminary design concept for the lower resolution FMS can be modified, at no extra cost, to conform to the port placements suggested in this document. Accordingly, the interface parameters tabulated in Section 4 completely replace the parameters presented in document RS-30, Nov. 6,

For monitoring purposes, the FMS will measure the X-ray source output in the annular region outside the X-ray beam that reaches the HRMA but inside the X-ray cutoff radius defined by the aperture in the center of the laser turning mirror. We assumed that the there would be no interference with the beam within a cone defined by the clear aperture of the 57.5 inch diameter of the gate valve 1707.33 feet from the X-ray source. We further assumed that the X-ray source was located ten feet behind the laser turning mirror. In order to provide sufficient room for the spectrometer apertures, we recommend that the diameter of the hole in the laser turning mirror be increased from 5/8 inch to one inch. In addition, the location of the FMS will shadow the apertures of the broadband flux monitors located 130 feet from the X-ray source. We recommend that the X-ray flux monitors should be repositioned to use the quadrant of the X-ray annulus around the +Z axis.

In addition to their placement in the annular region outside the beam of the HRMA, the spectrometers will be equipped with translation apparatus which would allow them to be moved into the axis of the X-ray beam in order to avoid any discrepancy in calibration due to a variation of the source spectrum as a function of angle.

To estimate the time required to measure spectral line intensities to a precision of 1%, we assumed that the X-ray source would be as strong at any line of interest as the source used to calibrate the VETA was at 8.3 Angstroms. That source was measured to produce 70 photons-cm^{-2}-sec^{-1} at 1700 feet. We assumed that the calibration sources for the HRMA would generate at least this much photon flux in any spectral line of interest.

Based on the information provided by SAO, we established a design goal for the crystal spectrometers of resolution, $\lambda/\delta\lambda$, in excess of 4000 over the range 1 to 10 keV and approximately 2000 from 0.5 to 1 keV. Double crystal Bragg spectrometers have intrinsically higher resolution than single crystal spectrometers because the double diffraction suppresses the wings of the diffraction peak. Double crystal spectrometers were therefore substituted for the single crystal spectrometers considered in our earlier study.

In our earlier study we had selected two Pouey spectrometers, combining a toroidal mirror and a plane, variably spaced grating, to cover the spectral ranges 20-60 Angstroms and 50-150 Angstroms. We established a design goal of resolution greater than 2000 at 0.5 keV and 3000 or more for energies under 300 eV. The resolution of the grating spectrometers is determined by two factors. The resolution of the spectrometer optics in projecting an image of the entrance slit on the focal plane and the spatial resolution of the focal plane detector. In order to improve the spectral resolution, we redesigned the spectrometer optics. In order to accommodate the HRI, we increased the dispersion of the gratings. Because the optical design is not independent of the dispersion, the designs of the two spectrometers were optimized by ray tracing. The ray tracings were performed by Instruments SA of Edison, NJ and their sister company, Jobin-Yvon of France, under subcontract to Radiation Science.

A 32 inch diameter port (designated 78K) has been provided for diagnostic instrumentation. It is located in the bottom (-Z side) of the guide tube at Station 26+85.56, approximately 14.5 feet from the end of the 3 ft. diameter tube. The crystal spectrometer can be mounted on this port. Because of the length of the grating spectrometers, however, only a portion of these instruments can be accommodated here. In our previous study, we attached the toroid-grating pairs to an invariant structure supported by the port and then attached the entrance apertures to another port closer to the source. We attached the detectors to a third port at the location of the spectrometer focal plane. In order to provide the freedom to reconfigure the optics as required for the higher resolution, we decided to attach the entrance apertures to an "optical rail" attached to the same invariant structure that holds the toroid grating pairs. This eliminates the requirement for one of the new ports. However, it would be difficult to position and align the optics with no access to the front portion of the instrument. We therefore recommend the installation of a 24 inch diameter access port on the -Y side of the guide tube for these purposes.

The spectra are detected by HRI cameras provided by SAO. Each of the spectra is dispersed along an 85 mm long focal plane. In order to keep the two spectra from interfering with one another, the optical paths are tipped away from the center line by flat mirrors at one degree grazing angle to the beam

direction. Each HRI must be moved along the dispersion axis in the focal plane in order to detect the entire wavelength range. While analyzing the system, we found that the HRI housings interfered with the direct beam when the sensitive areas of the HRIs were at the inboard ends of the two spectra. Fortunately, the HRIs can be repackaged easily to eliminate this problem. In order to accommodate the focal plane assembly, we recommend that the detector port on the +Z side of the tube suggested previously should be increased in size from 24 inch diameter to 32 inch diameter. The center of the detector port can be moved about 14 inches closer to the spectrometer optics to Station 26+81.

The overall layout of the FMS is shown in Figure 1. The interface parameters are tabulated in Table III of Section 4. The changes in the interface from our previous study are tabulated in Table IV.

2 Crystal Spectrometer

Figure 2 shows the design concept of the crystal spectrometer. Three double crystal spectrometers cover the wavelength range between 0.5 and 10 keV while sharing drive mechanisms. The three spectrometers move in concert. The double crystals are arranged in the "dispersive" configuration. A second crystal diffractor is located at the 2θ position that would be occupied by the detector in a single crystal spectrometer. The second crystal is rotated to the same angle relative to the beam striking it as the first crystal. A collimated detector is placed in the 2θ position relative to the second crystal. In this configuration, the wings of the crystal diffraction curve are suppressed and the total angular dispersion of the spectrum is doubled.

The choice of crystals is governed by the energy range to be covered. Silicon crystals cover the range from 10 keV to 2 keV. It is easy to obtain high quality silicon crystals in large sizes. The diffraction width of silicon at 10 keV is less than 10 arc-seconds. At 2 keV the diffraction width is about 1 arc-minute. Double crystal spectral resolution of 6000 has been reported, but this would require a total angular spread of about 6 arc-seconds at 10 keV. Most of the angular uncertainty at the small angle, short wavelength end of the spectrum is introduced by the size of the source. The result is that the resolution at 10 keV is no greater than about 2500. At lower energies, larger Bragg angles, this factor becomes less important. It is reasonable to expect resolution of at least 4000 for energies below 4 keV.

ADP (Ammonium Dihydrogen Phosphate) crystals cover the range from 1.2 keV to 6.7 keV. The rocking curve widths of ADP at 10° and 80° are approximately equal to those of silicon. The resolution at the short wavelength end of this crystal is also

reduced by the effect of source size, but this is less important because those energies will be covered by the silicon crystal at high resolution. Again it seems reasonable to expect resolution of 4000 or more over the range between 1.2 and 4 keV.

RAP (Rubidium Acid Phthalate) crystals cover the range from 0.5 keV to 2.7 keV. Because fewer crystal planes participate in the diffraction, the best spectral resolution that can be expected from RAP is about 1000 in the range below 1 keV. Fortunately, the grating spectrometer will provide higher resolution for energies below 0.6 keV.

We considered replacing the ADP crystals with Beryl crystals. The 2d spacing of Beryl is 15.96 Angstroms. Beryl crystals would extend the range of high (3000) spectral resolution down to 850 eV. Unfortunately, high quality Beryl crystals large enough for this application are nearly impossible to obtain. If the Beryl crystals were used only for energies below 2 keV, i.e. grazing angles larger than 23°, the crystal length could be reduced to 1.3 cm. for a 0.5 cm long aperture. This is a reasonable option if such crystals can be obtained.

The length of the crystal aperture is determined by the rocking curve of the crystal at 80° Bragg angle. In general, Bragg crystals are self collimating for a point source of monochromatic X-rays at finite distance. Rays which strike the crystal outside the angular range defined by the crystal's Bragg width are not reflected toward the detector. The effective slit width is therefore a function of the Bragg width and the distance to the source. At the high energy end of the crystal rotation, the effective slit width is only about a millimeter for Si and ADP. If the aperture is too narrow, though, rays which should reach the detector will be blocked. The low energy Bragg width of both Si and ADP is about one arc minute. Accordingly, we have defined the crystal apertures to be 1 cm long. This corresponds to an acceptance angle of ± 2.3 arc-minutes. This angle should permit collection of virtually all the energy in the spectral line. A slit width of 0.5 cm for a Beryl spectrometer would still collect a large fraction of the energy in the spectral line.

The three crystals will be mounted on a common shaft. The axis of rotation will be parallel to the crystal planes, but the crystals will pivot about different points on their surfaces. See Figure two. They will be coaligned in the laboratory, prior to installation. In this way, all three crystals can be aligned to the beam from the X-ray source with a single set of alignment stages. In addition, a single mechanism will move all three secondary crystals at twice the angular velocity of the primary crystal rotation. The secondary crystals will also rotate on a common shaft at the same rate as the primary crystals. The proportional counter detectors will be transported around the secondary crystals by a second 2θ drive. The crystals will be aligned in the laboratory prior to installation of the crystal

spectrometer. In this way, all three spectrometers can be aligned to the beam from the X-ray source with a single set of alignment stages.

The diffracted X-rays will be detected by end window proportional counters. The size of these counters is determined by the need to intercept the beam at all angular positions. The counter window materials, lengths and fill gases are determined by the efficiency requirements at the extremes of the energy ranges. The length of the proportional counters and the accompanying connectors and cables determine the length of the arm which separates the first and second crystal. The proportional counters must not block the aperture at any angular position. We have tentatively selected counter lengths of one inch. The two counters that detect X-rays with energies above 1 keV will be sealed. The sub-kilovolt counter may have to be a flow counter. Preamplifiers will be mounted in the vacuum, close to the counters but outside the X-ray beam.

The entire crystal spectrometer is mounted to the base plate through a set of stages which translate the spectrometer perpendicular to the beam and which rotate the spectrometer so that the crystal shaft is perpendicular to the beam. The absolute accuracy of the alignment of the crystals to the beam is not particularly critical, since this quantity is determined by in situ calibration of the alignment of the second crystal to the first for each run, but the crystal spectrometer is relatively sensitive to variations in alignment due to wobble or microphonics. No more than ± 5 arc seconds of movement in the orientation of the crystal axis can be permitted when the Bragg angle is small. This requirement is reduced as the minimum angle of crystal rotation increases.

Three 61 pin Deutch connectors will be required to convey low voltage power and logic signals to the crystal spectrometer. In addition, 3 SHV feedthroughs will be needed to carry high voltage to the proportional counter detectors. Nine tri-axial feedthroughs are required to carry data, timing information and signal injection. Two #4 VCR feedthroughs will be required for the sub kilovolt flow proportional counter. All of these feedthroughs should be mounted on the same baseplate as the spectrometer mechanism.

Instrument control and data acquisition can be handled by any small laboratory computer such as a PC or a Macintosh. Such a computer could be co-located with the experiment electronics rack adjacent to the diagnostic port (78K). Alternatively, signals to and from the electronics can be transmitted through an ethernet interface to the control room where they could be monitored by a workstation.

3 Grating Spectrometers

The overall layout of the two grating spectrometers is shown in Figure 1. Two spectrometers will be used. One spectrometer will cover the wavelength range from 20 to 60 Angstroms. The other will cover the range from 50 to 150 Angstroms. It is reasonable to expect good spectra over a factor of three in wavelength.

The spectrometers are of the Pouey design. A toroidal mirror is used together with a holographically formed plane grating to disperse a nearly stigmatic spectrum onto a flat focal plane suitable for detection by a two dimensional imaging array. The two spectrometers are tilted away from the axis by one degree turning mirrors.

The turning mirrors and the plate holding the apertures of the five spectrometers are attached to an "optical rail" which is attached to the invariant structure holding the optical parts of the spectrometers at port 78K. In order to avoid any loss of resolution or throughput due to thermal effects, the position of the front end optics should be controlled by materials having approximately the same coefficient of thermal expansion as the optics. Because the optics will be manufactured of fused quartz or a low expansion ceramic like Zerodur, this implies that the spacing of the optics should be controlled with a graphite epoxy or invar metricating structure. Even though the aperture plate and turning mirrors are located approximately 1.6 meters ahead of the toroidal mirrors, this is not a difficult requirement because the weight of these components is small.

Like all grazing incidence optical systems, the Pouey spectrometer is subject to aberrations, particularly, coma. These aberrations are more serious for the 20-60 Angstrom spectrometer whose grazing angle is two degrees, than they are for the 50-150 Angstrom spectrometer which has a four degree grazing angle. The effect of these aberrations can be determined primarily by ray-tracing.

The baseline system used a nominally 2400 groove/mm grating with a grazing angle of approximately two degrees. The 10 micron wide by 1 mm high entrance slit was located 1604.2 mm in front of the toroidal mirror. The toroid and the aberration-corrected, variably-spaced plane grating are separated by 375 mm. The angle of incidence on the grating is -87.96 degrees. The nominal exit angle is 84.02 degrees. The focal surface is a flat field 1229.2 mm from the grating center. In practice, the entrance pupil is not defined by the entrance slit. Rather it is set by the apparent size of the grating as projected onto the entrance slit by the toroid.

In this case, the aberrations introduced by the toroid are particularly bothersome. The spectrometer was ray-traced at

10 Angstrom intervals from 20 to 60 Angstroms. The only variable that made a significant difference in the resolution of the instrument was the size of the grating. In essence, reducing the size of the grating causes improperly aimed rays from the toroid to miss the grating and therefore to miss the focal plane. The nominal efficiency of the spectrometer is reduced thereby, but the missing rays did not contribute to the peak of the spectral line image anyway. Table I shows the resolution to be expected when the grating size is reduced from 160 x 6 mm to 60 x 8 mm. This design does not quite reach our design goal at 20 Angstroms, but it exceeds our goals at other energies.

Table I - Resolution of the 20-60 Angstrom Spectrometer

	.62	.41	.31	.25	.20
λ	20	30	40	50	60
	1429	2500	3333	3846	3000

The intrinsic resolution of the 50-150 Angstrom spectrometer is better because the grazing angle is increased and the grating pitch is reduced relative to the 20-60 Angstrom spectrometer. Therefore, a given angular deviation corresponds to a smaller wavelength deviation. Table II shows the resolution of the longer wavelength spectrometer. It's resolution is lower in the region of overlap with the higher energy spectrometer, but it is higher in the waveband that does not overlap.

Table II - Resolution of the 50-150 Angstrom Spectrometer

	.25	.18	.14	.11	.095	.083
λ	50	70	90	110	130	150
	2083	2593	3600	4583	4063	5000

Each of the toroidal mirrors will be optically aligned with its corresponding plane grating during assembly. Each mirror and grating pair will be mounted together as a unit which can be aligned to focus the spectrum on the detector. These optical elements will be mounted at the existing port at Station 26+85.56 along with the crystal spectrometers. Both the toroidal mirrors and the gratings are made of fused quartz and are coated with gold. The overall length of the spectrometer depends on the choice of grating period and on the resolution of the area detector selected to read out the spectrum. These quantities determine the overall resolution of the spectrometer.

The detectors will be mounted at a new port at Station 26+81. SAO has requested that we consider the use, if possible, of the HRI detectors. The HRI has adequate resolution for this purpose. Because the sensitive area of the HRI detector is 25 mm in diameter, it will be necessary to translate the detectors along the dispersion direction in order to image the entire 85 mm long spectrum from each spectrometer. In addition the detectors will be capable of movement for focussing and placement of the spectrum.

During the course of our analysis we realized that as presently packaged, the HRI detectors will block the X-ray beam directed toward the HRMA. In addition, the two HRIs could interfere with each other in certain situations.

The HRIs in use on the TMA and VETA-1 test programs were originally built in 1974 as brassboards for the HEAO-B program. They were designed to be bolted to the end of an X-ray test facility. They were not designed for use in vacuum and they were not packaged for minimum size because there were no requirements to do so at that time. The two units have subsequently been reworked to make them suitable for use in vacuum, but there has been no modification to the configuration of the basic package.

The present size of the HRIs renders them unusable as detectors for the grating spectrometers. The seven inch maximum diameter of the housing flange will block part of the central core of the beam when either detector is positioned to read out the long wavelength portion of the first order dispersion pattern of its grating.

The HRIs can be made usable by relatively simple repackaging. The basic size of the housing that holds the MCPs and the crossed grid readout is four inches in diameter. A new housing of that size can be fabricated and mounted on a standard six inch Conflat flange. The housing only needs to be two inches deep. It can have feedthroughs welded to the back surface just as the present housings do. The housing can be attached to a special 2 1/2 inch diameter gate valve modified to have a six inch flange on one side. A gate valve with a standard six inch flange has a much larger open diameter than is required to accommodate the one inch diameter active area of the HRI. Accordingly the housing should be attached to a special 2-1/2 inch diameter gate valve modified to have a six inch flange on one side. This will avoid the weight and size penalty of the larger valve.

The coupling capacitors, preamplifiers and front end electronics that make up the rest of the present detector package can be removed from the HRI assembly, avoiding excessive weight and volume on the moving mechanisms. They can be moved outside the vacuum chamber or they can be placed inside the chamber on or near the detector access port. The experience of the HRC program demonstrates that a six foot cable length from the preamplifiers to the front end electronics is acceptable. The outputs from the grid to the preamplifiers can be fed through the port using standard feedthroughs. The voltages on the wires are approximately 250 volts, which is well within the 1000 volt pin-to-pin rating of the feedthroughs.

One additional change will be required which is independent of the repackaging of the HRIs. The present MCPs should be replaced by a chevron plate having a front MCP with a non-zero bias angle. The zero bias angle plates that are

currently used in the HRIs are well suited to detecting the converging beam of radiation from an X-ray telescope, but they may not have sufficient quantum efficiency for X-rays which strike the plate at angles nearly perpendicular to the face of the plate, nearly parallel to the individual tubelet axes. Because the MCPs would probably require replacement in any event, this is not regarded as a significant change.

Two additional 61 pin connectors will be required at port 78K to service the mechanisms which position the mirror-grating optical systems. The new port at Station 26+81 will need at least three 61 pin Deutch connectors, two SHV connectors for detector high voltage, and four tri-ax connectors. Two more 61 pin connectors will be needed if the HRI electronics are mounted outside the vacuum chamber.

The data will take the form of four images of the spectrum from each spectrometer for every spectrum measurement interval. While these spectra cover the full extent of the detector in the direction of dispersion, they need only cover a fraction of the detector in the opposite direction, e.g. the central quarter. Thus the maximum data volume is approximately equivalent to one full HRI image every five or ten minutes. Software will be required to convert the detector images to spectra by summing data as a function of wavelength. Macintosh software for this purpose already exists at Radiation Science. This software is adaptable to other computer systems.

4 Interface Parameters

Table III -- FMS Interface

VACUUM INTERFACE:

The spectrometer will be attached to port 78K at Station 26+85.56. Two additional ports will be required. A 24 inch diameter port on the -Y side of the guide tube at Station 26+87 and a 32 inch port on the +Z surface at Station 26+81. Port 78K and the new port at Station 26+81 should be equipped with locating pins which define the direction perpendicular to the source (the Y axis) within ±1°.

SPECTROMETER WEIGHT:

Port 78K: 60 kg
New port at 26+81: 25 kg

MECHANICAL ENVELOPE:

See figures.

STABILITY:

The relative positions of port 78K and the port at Station 26+81 must not change by more than 10 microns in the Y-direction or the Z-direction over the data sampling interval.

The orientation of the axis normal to the baseplate of port 78K may not rotate about the Y axis by more than ±2 arc seconds over the grating spectrometer data sampling interval or by more than ±5 arc-seconds about the Z axis during the crystal spectrometer data sampling interval.

TEMPERATURE:

Operating -- 70±5 F
Operating Stability -- ±2 F

Storage -- 70±5 F

ELECTRICAL:

Port 78K -- 5 61 pin
3 SHV
9 tri-axial

Detector port
3 or 5 61 pin
2 SHV
4 tri-axial

GAS:

2 VCR #4 feedthroughs on Port 78K

DATA:

TBD (see text)

Table IV -- FMS Interface Changes from RS-30

This list summarizes the changes in the proposed interface between the FMS and the AXAF test facility from the interface presented in Radiation Science report RS-30. These changes result from modifications to the preliminary design in order to accommodate the requirement for higher spectral resolution.

Previous Study	**Present Study**
16" Aperture port on +Z surface at Station 26+93.1	Use Access port 79E; new hinged 24" port on -Y surface at Station 26+87.
Aperture port pierced for two 61 pin connectors.	No feedthroughs on port 79E or new port at Station 26+87.
Port 78K pierced for 4 61 pin connectors, 3 SHV connectors, 9 tri-axial connectors, 2 VCR #4 gas feedthroughs.	Port 78K pierced for 5 61 pin connectors, 3 SHV connectors, 9 tri-axial connectors, 2 VCR #4 gas feedthroughs.
24" Detector port on +Z surface at Station 26+79.8	New 32" Detector port on +Z surface at Station 26+81.
Detector port pierced for 3 61 pin connectors, 2 SHV connectors, 4 tri-axial connectors.	Detector port pierced for 5 61 pin connectors and 2 SHV connectors, if HRI electronics outside vacuum. No change if HRI electronics inside.
Mass attached to port 78K less than 40 kg.	Mass attached to port 78K less than 60 kg.
Angular position of ports arbitrary.	Port 78K and new detector port pin registered to $\pm 1^{\circ}$.

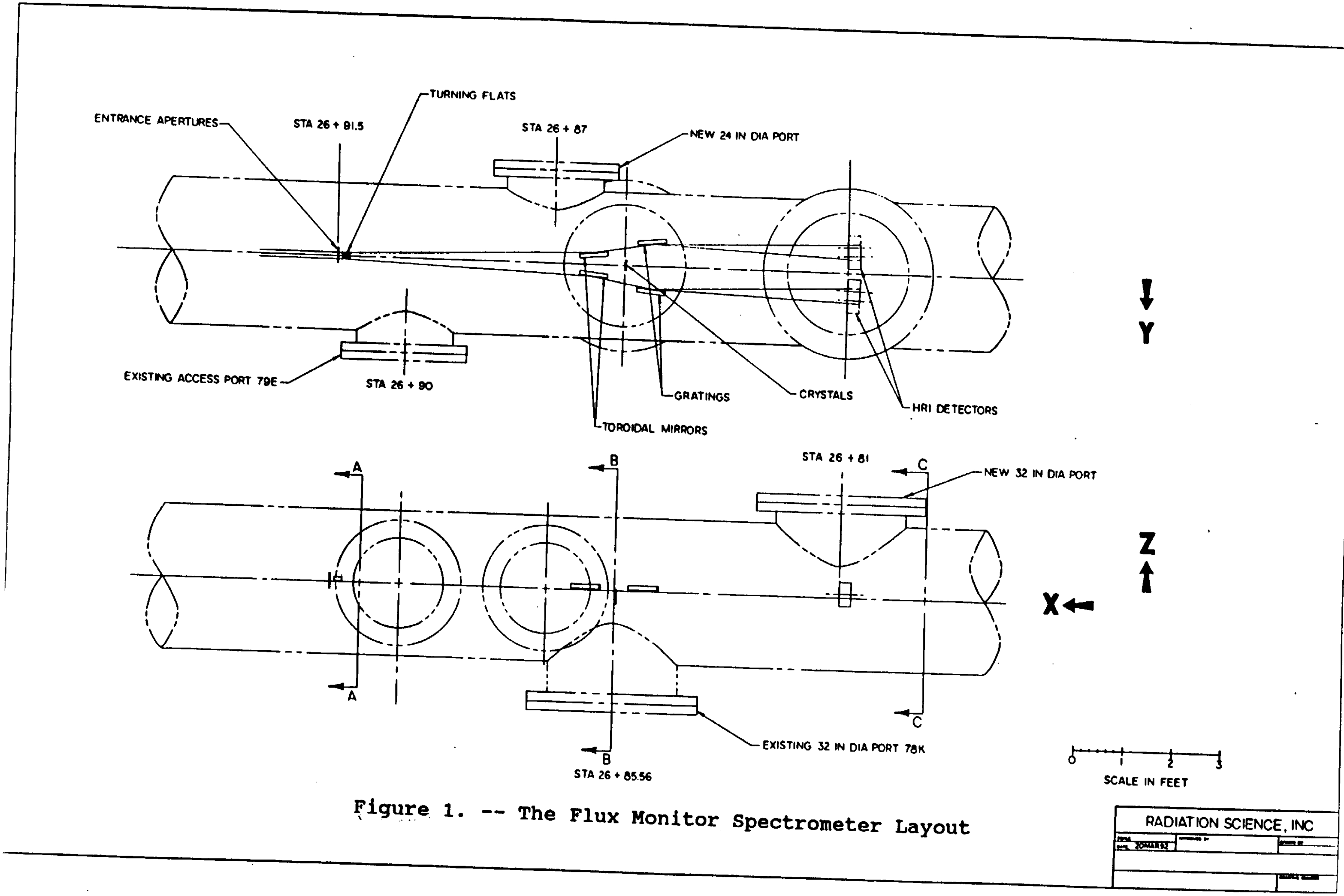


Figure 1. -- The Flux Monitor Spectrometer Layout

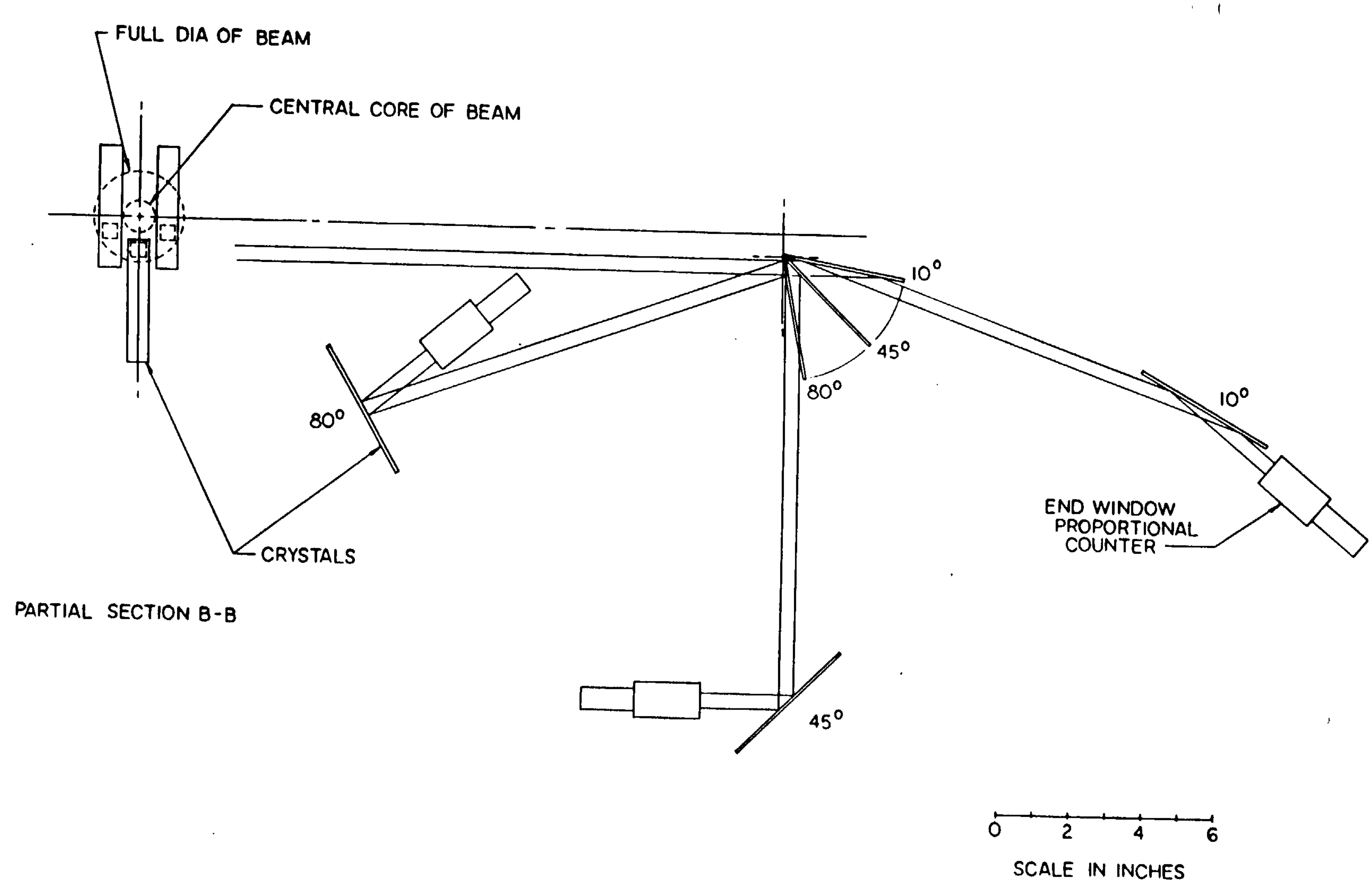


Figure 2. -- Double Crystal Spectrometers

RADIATION SCIENCE, INC

DATE 20MAR92

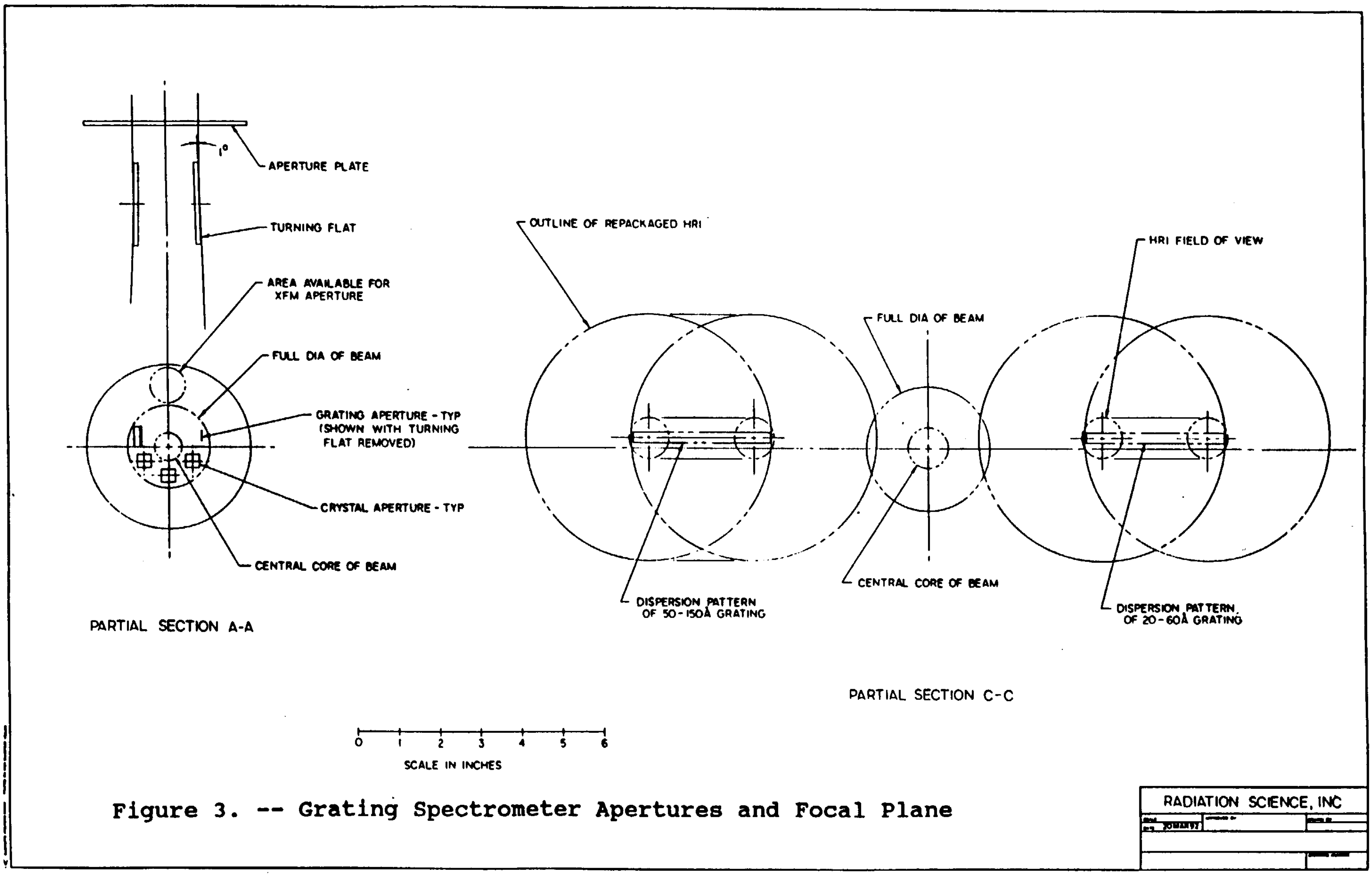


Figure 3. -- Grating Spectrometer Apertures and Focal Plane